ASSESSMENT OF THE ASR EXPANSION OF CONCRETE MADE WITH RECYCLED CONCRETE AGGREGATES

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Abstract

The amount of construction and demolition waste is increasing all over the world. Most of this waste consists of concrete and masonry. These waste materials are very suitable to be recycled. After carrying out an advanced recycling procedure, it's possible to produce high-quality recycled aggregates. Until now, most of these aggregates are used in low grade application as in road foundations. In Flanders, where the market in road works is now almost saturated, using more recycled concrete aggregates in structural concrete could provide the answer for the growing stock. Another advantage is that less natural aggregates, which are finite in quantity, have to be obtained from quarries or sea- and riverbeds. This is both cost-saving and environment-friendly. Before this relatively new application can be fully implemented, the behaviour and characteristics of recycling concrete aggregates have to be known. Some uncertainties hinder the large scale use of recycled concrete aggregates in structural concrete. One frequently claimed uncertainty is the possible alkali-silica reaction.

This paper discusses the results of an investigation on the alkali-silica expansion of recycling concrete with different replacement rates of recycled aggregates and different types of cement. In this study, only recycled concrete aggregate is investigated as recycled aggregate. Both coarse and fine recycled concrete aggregates are examined. The results are also compared with other studies.

Keywords: *Recycling Concrete, Recycled Concrete Aggregate, Alkali-Silica Reaction, Accelerated Test Methods*

1 Introduction

Sustainable development has become a very important topic in the last decades. Issues like energy consumption and carbon dioxide emissions are very current. In the construction sector a lot of actions are taken and still have to be taken to evolve to a sustainable building industry. This is not only a matter of energy performance of buildings but also of sustainable materials management, since the construction sector uses about 40 to 50 % of all resources. Not only the performance of the structures during their life time and production of the materials used must be looked at, but also the end-of-life treatment. The waste stream arising from the construction and demolition of buildings and infrastructure, is indeed enormous. The major part of this waste consist of concrete rubble, masonry rubble and mixed debris. [1] This debris can be processed into reusable recycled aggregates to replace the ending natural aggregates. With regard to the applications, low-grade applications such as foundation material in road construction, is envisaged in the first instance. However, there are many high-quality applications with added value in which recycled aggregates can be used succesfully. Research into applications with added value is of great importance, since in the future there will be insufficient low-value applications to discharge the increasing amount of recycled aggregates. Furthermore, a breakthrough for the widespread use of recycled aggregates will be possible if uncertainties concerning their characteristics and performance have been examined thouroughly. [2]

The properties of the recycled aggregates, which provide the uncertainties for their use, are the lower inherent strength, the impurities in the rubble and the variability of the characteristics. The latter is due to the fact that the origin of the construction waste is unclear. It could be from road-pavements or ordinary buildings, complete or selective demolition. Another major difference between natural and recycled aggregates is that recycled aggregates are composed of the original granulate and are covered with a layer of attached old cement mortar. Due to the attached cement mortar, recycled aggregates are porous and therefore they have a lower density and higher water absorption. Whether these differences with the natural aggregates cause adverse performance must be examined, before any large-scale use can be made and a proper regulatory framework can be provided. [2] [3]

One of the questions that arise when looking at the use of recycled concrete aggregates (RCA) in new concrete applications, is the potential alkali-silica reaction (ASR). This paper discusses some results of an investigation on the alkali-silica expansion of recycling concrete (RC) with different replacement rates of RCA and different types of cement.

2 Alkali-Silica reaction

For a long time, the selection of aggregates for use in concrete was based solely on the physical properties, such as particle size distribution, particle shape and density. Almost no attention was paid to the chemical and mineralogical composition of the aggregates. However, concrete is a highly alkaline environment, with pH values up to 13. In the 30's for the first time the chemical reaction between the solution in the pores of concrete and silica-rich aggregates, was proposed. It has already been noted that the formed expansive reaction products lead to crack formation, to a reduction in the strength and a limited life of the concrete structure. Thus, for the first time the alkali-silica reaction was noted. Later, several by this reaction caused damages were found. It became clear that the chemical stability of aggregates should be evaluated. [4]

There is a set of alkali-aggregate reactions which can occur between some of the aggregates and alkalis from the liquid in the pores. The alkali-silica reaction (ASR) is for Belgium the most relevant variant of this group. The components of the aggregates, which participate in the reaction, contain reactive silica (silicic acid). This can take the form of opal, chalcedony, christobaliet, tridymite and crypto-crystalline quartz. The alkalis present are Na_2O and K_2O. They can come from all constituents of the concrete (cement, aggregates, mixing water, admixtures, additives). However, they can also be supplied from the outside environment (NaCl as de-icing salt, seawater, brackish water, ...). During the reaction process, only the free, soluble alkalis play a role. [5]

2.1 Expansion testing

Expansion tests are often used for the assessment of the alkali-silica reaction in concrete or mortar. Some tests are ‘long term tests’, but more and more ‘accelerated testing methods’ are being used these days. Further, use can be made of chemical tests and petrographic examination to determine the reactivity of the aggregates, but these test are expensive and also take some time and therefor the industry is rather interested in the accelerated methods.

Long term testing can be done according to *ASTM C 227: Test Method for Potential Alkali Reactivity of Cement–Aggregate Combinations (Mortar–Bar Method)*. The reliability of this method is questioned in many literature. Another long term method is: *ASTM C 1293: Test Method for Concrete Aggregates by Determination of Length Change of Concrete Due to Alkali–Silica Reaction*. This test doesn't provide realistic values for the total expansion that can occur but indicates the possibility of excessive ASR-expansion. Furthermore there are some Canadian, French, British Standard Methods and RILEM procedure, but all of them provide a result similar to that of ASTM C 1293.

Accelerated testing can be done according to *ASTM C 1260: Test Method for Potential Reactivity of Aggregates (Mortar–Bar Test)*, which will provide a result after 16 days for the potential ASR of aggregates. This method only tests the aggregate and not the combination of aggregate and cement in concrete. Sometimes the results for the aggregates show potential for ASR while in reality there is no damage found in the concrete.

There is also a chemical test that can be used to evaluate the potential ASR-reactivity: *ASTM C 289: Standard Test Method for Potential Alkali–Silica Reactivity of Aggregates (Chemical Method)*. This method is also not very reliable. [6]

3 Investigated materials

3.1 Natural aggregates

Three types of natural aggregates are used in the experimental program: sand 0-4mm, broken limestone 0–4mm and broken limestone 6-20mm. The limestone aggregates comes from a Belgian limestone quarry, which is not exactly known. Probably this concerns Belgian Blue Stone. This is a relatively pure crinoids limestone.

3.2 Recycled concrete aggregates

For this investigation RCA was chosen derived from three different locations. The RCA fraction 0–20mm was divided into a fraction 0–8mm and 8-20mm. RCA-1 came from a recycling and concrete plant. This RCA-1 is processed out of mixed C&D waste from demolition of buildings and from road construction. RCA-2 came from another recycling plant owned by a company specialized in road-work and infrastructure. RCA-2 comes from demolished pavements. RCA-3 is made from residues from the production of concrete sewerage tubes. Some tubes from the production didn't comply with the requirements and were demolished. This rubble was processed as RCA-3. All three RCA's did comply with the COPRO quality assessment for recycled aggregates.

3.3 Cement

Three types of cements are applied in the experiments to assess their impact. The first kind is a Portland cement (CEM I 52.5 N) with Na_2O-equivalent of 0.80 %. The two other types of cement are blast furnace cements, of which one with a low alkali content (CEM III / A 42,5 N (LA)). The ordinary blast furnace cement has a Na_2O-equivalent of 0.77 %. For the blast furnace cement having a low alkali content, the Na_2O-equivalent is 0.60 %.

4 Expansion tests on recycling concrete made with RCA

4.1 The experimental program

To test the coarse RCA fraction 8–20mm on their ASR-reactivity, an expansion test is used. The basis of this expansion test is derived from the American standard ASTM C 1293 and the Canadian Standard CSA A23.2-14A. Test samples of recycling concrete are made, kept in a certain condition for a certain time in which the variations in length are measures. Based on the expansion that appeared the susceptibility to ASR-reactivity is concluded. Some adaptations were made to the testing method described in the standard. First of all test-samples size 100 mm diameter and 150 mm height are retrieved by means of a core-drill. The size of the test-samples in the standard is 75 mm x 75 mm x 600 mm. By taking out the test-samples by core-drilling, the RCA will come much faster and better in contact with the NaOH-solution (1M). The test-samples are put immediately in the NaOH-solution. As a result there is no change in humidity during the test and the water in the pores will get the same high pH and the increased alkalinity will lead to the solution of more reactive silica derived from reactive RCA. The alkalis will then react with the dissolved silica, leading to the formation of the expansive alkali-silica-gel. The speed, with which an aggregate will react, is dependent on the basicity of the pore fluid. Below a certain pH-value, a certain kind of granulate will not respond. [7] The temperature used to submit the test-samples to NaOH-solution during the experimental program is 38 °C. A higher temperature such as 80°C could be used to speed up the test, but the results tend to be less reliably. The samples in recycling concrete were cured during 24 h at 23 °C and RV100 % immediately after casting. After one day curing the cores are drilled and put back for another 24 h in the curing room under the same curing-conditions. Next the samples are submerced in a NaOH-solution (1M) and kept on a temperature of 38 °C. The first initial measurement is taken after drying in an oven for 24 h. This measurement must be done as quickly as possible to avoid changes in length due to cooling of the specimen. Every month an expansion measurement is made. The last measurement is made 6 months after the first initial measurement.

4.2 Composition of the recycling concrete

Various recycling concrete mixtures (RC) are examined and compared to a reference ordinary concrete mixture (OC). The RC are made of concrete 0/4 sand, limestone 6/20, coarse RCA fraction 8–20mm, cement and water. The differences between the mixtures are in the kind of RCA, the replacement rate and the type of cement. Up to now is simply a replacement content of 20 % within the standards authorized in Belgium. To strive forward herein, the tests are carried out with replacement rates of 30 and 100 %. No use admixtures, such as superplasticizer, were used. These substances however have no influence on the alkali-silica reaction. The notation of the mixtures is as follows: ‘ref’ stands for reference OC, ‘RCAx-yy %’ stands for RC made with yy % of RCA number x. Example: RCA2–30 %.

The W/C-ratio is 0,55 and the cement dosage is 310 kg/m³. The concrete composition is calculated for an ideal concrete skeleton according to Bolomey’s packing method. Therefor the particle size distribution of all aggregates used was determined on beforehand. The higher water absorption of the RCA’s is compensated by adding a calculated extra amount of water, keeping the effective W/C-ratio constant: W/C_{eff} = 0,55. A typical composition for the recycling concrete is given in Table 1.

Tab. 1 *Typical composition for RC used in the experiments*

Composition	Density ρ_a [kg/m³]	Dosage [kg/m³]
CEM I 52,5 N	3,10	310,00
Water (W/C_{eff} = 0,55)	1,00	170,50
Sand 0–4 mm	2,65	814,17
Limestone 6–20 mm	2,71	772,58
RCA 8–20 mm	2,63	321,33
	Total for 1 m³ concrete	2338,59 [kg]
Extra added absorption water		*32,02 L*

Test are performed to check the mechanical properties of the different concrete mixtures. All mixtures complied with the concrete strength-class C25/30, as designed. The results are not detailed further in this paper.

4.3 Expansion tests on mortar with fine RCA

In addition to the experimental program with recycling concrete made with coarse RCA, expansion test are also performed on mortar prisms made with fine RCA 0–8 mm. The testing method is according to ASTM C 1260. As mentioned before, this accelerated method is not suitable to test coarse RCA, but may well provide useful information when using fine RCA in mortar. In this experimental program, CEM I 52,5N was used. Prisms are made of size 25 mm x 25 mm x 250 mm. The mix proportion cement/aggregate is kept constant at 1/2,25 [M/M] and the W/C-ratio is 0,47. The test specimens are submitted to a NaOH-solution (1M) of 80 °C. The expansion is evaluated at 14 days after the initial measurement before submission to the NaOH-solution at one day of age.

5 Results

5.1 Expansion measurements on RC with coarse RCA

To measure the expansion a testing facility is made. The test samples are always put in the same way in the measurement apparatus. The expansion is measured up to 0.001 mm. The result is expressed in percentage to the initial measurement. There is no risk of ASR-reactivity as long as the expansion is less than 0.040 %. Above this value additional testing should be done to determine the risk of ASR-reactivity.

The influence of the replacement rate of coarse RCA in RC is examined by using one type of cement, CEM I 52,5N, and two replacement rates of 30 %, respectively 100 %. The results show that for 30 % and 100 % replacement rate of coarse RCA in RC, both RCA1 and RCA2, show no risk of ASR-reactivity. RCA3 however shows a potential ASR-reactivity. Figure 1. This is probably due to the fact that RCA3 is made of disapproved recently made sewerage tubes. They were made using OPC , but they were never used and so no alkali leaching occurred. Therefor it’s expected that this RCA3 reacts more than the other RCA’s. More research must be done to support this conclusion.

The influence of using a ‘low alkali cement’ is investigated by making samples using the three kinds of RCA with a replacement rate of 30 % and using two types of cement: CEMIII/A 42,5N and CEMIII/A 42,5N-LA. The results are shown in Figure 2.

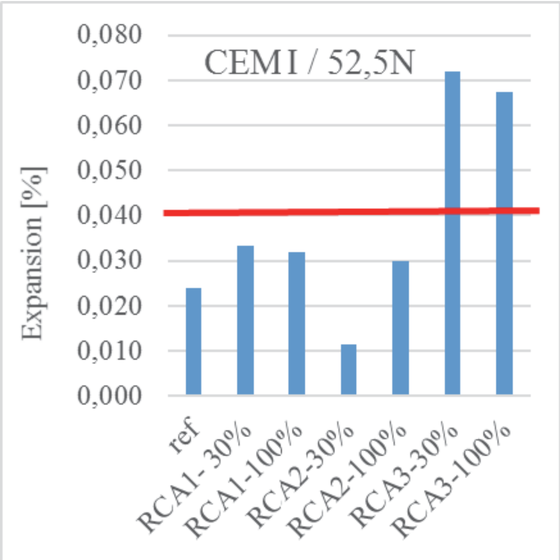


Fig. 1 *Influence of the replacement rate of RCA in RC on the ASR-reactivity*

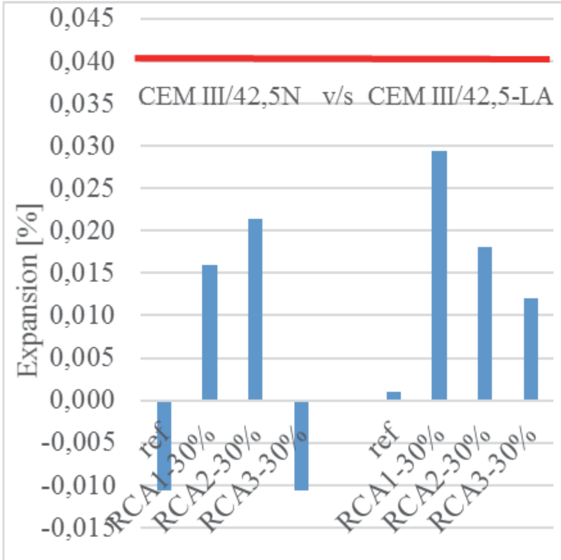


Fig. 2 *Influence of using low-alkali cement on the ASR-reactivity of RCA*

It can be seen that for both types of cement there is no risk for ASR-reactivity, not even for RCA3 that showed some potential risk when using CEM I 52,5N. The use of blast furnace cement CEM III/42,5N or CEM III/42,5N – LA, seems to give sufficient protection to ASR-reactivity. In all cases the expansion was less when using blast furnace cement compared to using Portland Cement.

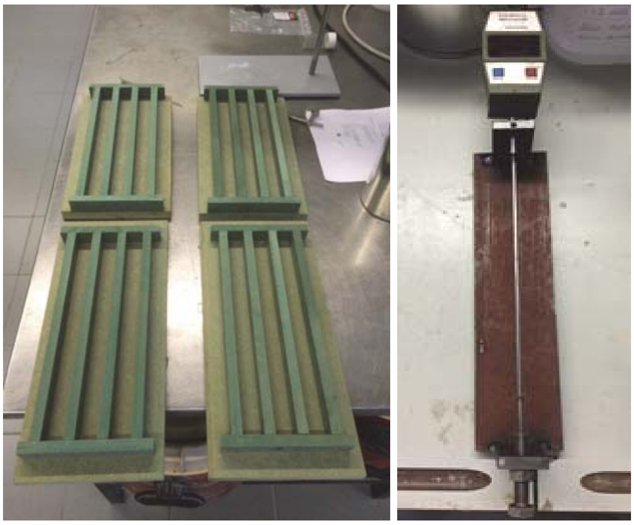
5.2 Expansion measurements on mortars made with fine RCA

Expansion tests are made on mortar prisms size 25 mm x 25 mm x 250 mm. The molds and the measuring device are shown in Figure 3. At both ends of each prism a fixed conic point is glued. This way the specimen are always put in the same orientation in the measuring device. The electronic meter is calibrated using a calibration rod, as seen in Figure 3.

The results of the expansion measurements are shown in Figure 4. There are three zones distinguished to determine the potential ASR-reactivity: a ‘safe’ zone when the expansion is less than 0,10 %, a zone of ‘potential risk for ASR’ when the expansion is more than 0,20 %, and a zone in-between where it is unclear if there is a risk for ASR-reactivity and where additional testing should be done.

During the measurements the glued conic endpoint released from the specimen ‘RC2b’ and ‘ref-a’. No results can be given for these specimens.

As seen from the results, the fine fractions RCA1 and RCA3 should be examined further for their potential ASR-reactivity, since they have just entered the “unclear” zone. Probably additional testing will show that for RCA1 there is no risk for ASR-reactivity since they just entered the ‘unclear’ zone. RCA3 definitely must be checked further. The higher potential risk for ASR of RCA3 could come from the fact that is RCA is derived from early age crushing of concrete made with Portland Cement.



(a) (b)

Fig. 3 *Expansion measurements on mortar prisms: (a) molds; (b)measuring device with calibration rod*

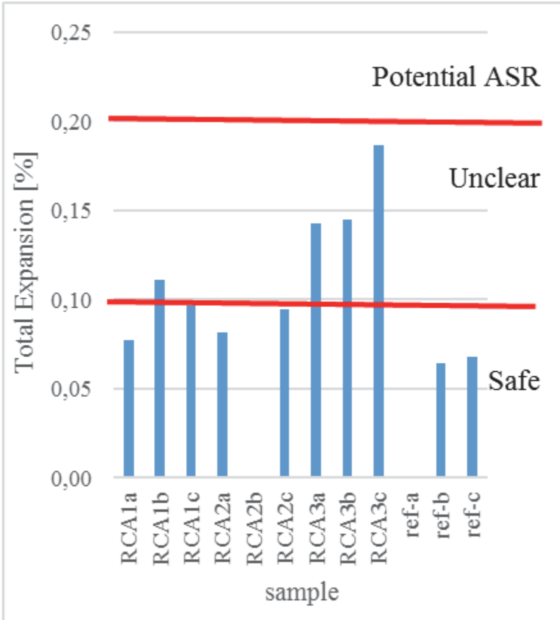


Fig. 4 *Potential ASR-reactivity of fine RCA in mortar*

6 Conclusions

Recycled concrete aggregate (RCA) has a strong potential to be used in recycling concrete (RC). The properties of coarse RCA comply with the standard for aggregates for use in concrete. Fine RCA contains more old mortar paste and can contain other impurities that could influence the chemical reactivity such as ASR.

Expansion test on RC with replacement of 30 % and 100 % coarse natural aggregates by coarse RCA, results in a positive evaluation for two samples of RCA. A third sample derived from disapproved freshly produced concrete sewerage tubes. Here the potential ASR-reactivity can be linked to the Portland Cement used in the production of the tubes and the fact that no alkali-leaching has appeared causing a more severe environment in which potential ASR-reactivity can be initiated.

The use of blast furnace cement and low-alkali cement adequately protects RC against potential ASR-reactivity when 30 % coarse RCA is used.

Using the fine fraction of RCA (0–8 mm) seems also possible. Expansion measurements performed on mortar prisms indicate the possible use of fine RCA in RC. Not all mixtures indicated to be safe. Some mixtures indicated that additional testing is needed. No mixture indicated a potential risk for ASR-reactivity.

More research needs to be done to look into the ASR-reactivity of recycled concrete aggregates as well as on the long term and accelerated testing methods.

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